INTERFERENCE SUPPRESSION FOR WIRELESS LOCAL AREA NETWORK AND LOCATION SYSTEM

Related Application

This application is based upon prior filed copending provisional application Serial No. 60/259,013, filed December 29, 2000.

Field of the Invention

This invention relates to the field of wireless local area networks (WLAN), and more particularly, this invention relates to wireless local
5   area networks that provide mobile device location and a location system for locating objects within a monitored environment.

Background of the Invention

10   Wireless local area networks (WLAN) and real time location systems (RTLS) are becoming more commonplace as the use of portable computers, such as "laptop," "notebook," and "pen" computers become increasingly common in office environments and other
15   locations. Examples of real time location systems and the circuitry and algorithms used in such real time location systems are described in U.S. Patent Nos. 5,920,287; 5,995,046; 6,121,926; and 6,127,976, the disclosures which are hereby incorporated by reference
20   in their entirety. Examples of a real time location system that is operative with a wireless local area network are disclosed in commonly assigned copending

utility patent application serial no. 09/997,282, filed November 29, 2001, and copending utility patent application serial no. **XX/XXX,XXX**, entitled "Wireless Local Area Network System with Mobile Access Point

5   Station Determination," filed December 17, 2001, the disclosures which are hereby incorporated by reference in their entirety.

In many of these types of systems, the amount of signal interference continues to increase to the

10   point that some of the communication systems lose their effectiveness.   There are some techniques that mitigate these effects, such as the use of spread spectrum and altenna diversity, as disclosed in the above identified patents and applications.   In any event, if the

15   wireless and real time location networks increase in number, the spread spectrum and diversity techniques are not sufficiently effective.

In the wireless environment, such as a wireless local area network and real time location

20   system, the environment is crowded with a number of communication signals and other interfering signals that occupy the same frequency bands or channels. Also, the environment is typically contaminated by multipath reflections from both the desired

25   communication signal emanating from a desired transmitter, such as a mobile device, TAG, or mobile access point, and interfering signals emanating from interfering sources, such as other networks and antennae.   Reflections can occur by wave reflecting

30   services, including walls, buildings, other antenna, natural earth landmarks and other reflecting sources known to those skilled in the art.

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Summary of the Invention

It is therefore an object of the present invention to provide a wireless local area network and location system that suppresses interference of
5   unwanted signals.

The present invention advantageously uses phase-temporal interference processing (PTIP) for interference suppression. Because of the increased speed of digital devices and communication circuits, it
10   is possible to digitize fast enough to manage both phase and multipath delays. For example, within the 2.4 GHz unlicensed ISM band, the wavelength is less than five inches, representing a peak-to-peak time of approximately 0.4 nanoseconds. It is possible to use
15   the present invention with a two-channel system or any other number of channels to enhance performance.

In accordance with the present invention, a wireless local area network includes a plurality of access point stations that receive and transmit
20   communication systems. A processor is operatively connected to each of the access point stations to process communication signals received from a mobile station in communication therewith. A processor weighs delayed versions of at least one interference signal by
25   controlling amplitude and phase with weighting functions W_1, W_2 ... W_n and summing any resultant weighted replicas to determine an approximation of the disbursed interference for cancelling interference. An interference detector and controller provides a control
30   loop for minimizing the total amount of interference.

A system antenna and interference receiving antenna are included. The interference receiving antenna can be a high gain antenna and directed for receiving an interference signal under high gain. The
35   system antenna can include two system antennas spaced

in diversity. The mobile station could include a mobile access point station that receives and transmits communication signals within the wireless local area network or a mobile device, such as a tag transmitter associated with an object.

In one aspect of the invention, a tapped delay line, summer, controller and interference detector circuit are operatively connected to the system and interference receiving antenna for weighting the delayed versions of at least one interference signal by controlling the amplitude and phase with the weighting functions and summing any resultant weighted replicas to determine the disbursed interference.

In yet another aspect of the present invention, a mobile station is in communication with the plurality of access point stations. A processor is operatively connected to each of the access point stations and operative for processing communication signals received from the mobile station and determining which communication signals are first-to-arrive signals and conducting differentiation of the first-to-arrive signals to locate a mobile station. A processor can be positioned at each access point station for determining first-to-arrive signals. A processor can receive any determined first-to-arrive signals from each access point station and conduct differentiation of the first-to-arrive signals. The processor can be operative for determining first-to-arrive signals based on a common timing signal.

In yet another aspect of the present invention, a location system locates objects within a monitored environment. The location system includes a tag transmitter associated with each object within the monitored environment and operative to transmit a signal encoded with information representative of the

identification of the object. A plurality of spaced
monitoring receivers receives signals from tag
transmitters. A processor is operative with each of
the spaced monitoring receivers and processes signals

5   received from tagged transmitters for determining which
signals are first-to-arrive signals and conducting
differentiation of the first-to-arrive signals to
locate an object and associated tag.

A processor weighs delayed versions of at

10   least one interference signal by controlling amplitude
and phase with weighting functions W_1, W_2 ... W_n and
summing any resultant weighted replicas to determine an
approximation of the disbursed interference for
cancelling interference. The processor can be

15   operative for determining which signals are first-to-
arrive signals based on a common timing signal. An
interference detector and controller circuit can
provide a control loop to minimize the interference. A
system antenna and interference receiving antenna can

20   be included. Two system antennas can be spaced in
diversity. A processor can be positioned at each
monitoring receiver for determining first-to-arrive
signals, A location processor can receive any
determined first-to-arrive signals from each monitoring

25   receiver and conduct differentiation of the first-to-
arrive signals.

In yet another aspect of the present
invention, the spaced monitoring receivers further
comprise a system antenna and interference receiving

30   antenna. A tapped delayed line, summer, controller and
interference detector circuit are operatively connected
to the system antenna and interference receiving
antenna for weighting delayed versions of at least one
interference signal by controlling amplitude and phase

35   with weighting functions W_1, W_2 ... W_n and summing any

resultant weighted replicas to determine an approximation of the disbursed interference for cancelling interference.

5 **Brief Description of the Drawings**

Other objects, features and advantages of the present invention will become apparent from the detailed description of the invention which follows, when considered in light of the accompanying drawings
10 in which:

FIG. 1 is an overall system diagram of a wireless local area network and location system of the present invention.

FIG. 1A is a system diagram showing the
15 general architecture of a tagged object tracking and location system that is operative with the present invention.

FIG. 2 is a system diagram showing receivers having spaced antenna for receiving uncorrelated
20 versions of a desired signal and uncorrelated versions of interference.

FIG. 3 is a system diagram showing a prior art approach used by many interference suppression systems where the interference (I) is subtracted from
25 the contaminated but desired signal (S+I).

FIG. 4 is a graph of a signal illustrating how it can be changed with one reflection where the reflection is delayed one symbol time and the phase is 180° so that the two signals are subtracted.

30 FIG. 5 is a system block diagram of the present invention showing the phase-temporal interference processing (PTIP) system for interference suppression using a tapped delay line, summer, interference detector and controller.

FIG. 6 is another system block diagram showing dual diversity antennae and a third input as a tertiary antenna where interference can be removed from both system inputs of channel A and channel B.

5   FIG. 7 is another system block diagram showing two diversity system antennae and a controller that operates to remove interference from each side by subtracting a replica interference from the other antenna in a bilateral, symmetrical fashion.

10   FIG. 8 is a high level block diagram of one example of the circuit architecture that can be used as part of a processor for determining first-to-arrive signals.

FIG. 9 is another high level block diagram of

15 an example of the circuit architecture that can be used with the present invention for correlation-based RF signal processors.

Detailed Description of the Preferred Embodiments

20   The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should

25 not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like

30 elements throughout.

The present invention advantageously provides a wireless local area network and a location system for locating objects in a monitored environment having a reduced and suppressed interference. The present

35 invention is an interference reduction system that is

applicable in a wireless local area network and real time location systems used with tagged transmitters. It is applicable in a wireless local area network with access point stations that locate a mobile station,

5   TAG, or mobile access point station. Examples of such systems potentially operative with the present invention are disclosed in the incorporated by reference U.S. Patent Nos. 5,920,287; 5,995,046; 6,121,926; and 6,127,976. A wireless local area

10   network with real time location system capability are disclosed in commonly assigned, copending utility application serial no. 09/997,282, filed November 29, 2001, and copending utility patent application serial no. XX/XXX,XXX, filed December 17, 2001, entitled

15   "Wireless Local Area Network System with Mobile Access Point System Determination."
          These wireless local area network and real time location systems as described can use two antennas for diversity reception. The present invention can

20   capitalize on a multi-channel receiver and process the signal environment and provide substantial signal-to-interference improvement. In the present invention, a phase-temporal interference processing (PTIP) system allows interference suppression. With faster digital

25   switching and higher technology systems now available, the present invention can digitize fast enough to manage phase and multipath delays at smaller wavelengths. For example, at 2.4 GHz in the common unlicensed ISM band, the wavelength is less than five

30   inches, representing a peak-to-peak time of approximately 0.4 nanoseconds. Although the present invention is explained relative to a two-channel system, the present invention is not limited to two channels and can be used with any number of received

35   channels to enhance performance.

As is known to those skilled in the art, when a signal is transmitted in a multipath dominated environment, reflections create copies of the signal, arriving disbursed in time-of-arrival (TOA) and

5   disbursed in direction-of-arrival (DOA). The signal paths to two receive antennas are different (uncorrelated) when two receive antennas are separated by a few wavelengths. In the illustrated examples, it is possible to use a five wavelength separation,

10 although the actual value chosen for the separation distance is sometimes subjectively chosen by those skilled in the art.

FIG. 2 illustrates a typical prior art wireless system **10** having two receivers **12** with

15 associated system antenna **14,** a source of interference **16,** a water tower **18** as a signal reflecting source, a transmitter **20,** such as a TAG transmitter or wireless local area network unit (for example an access point station), and another reflecting source **22,** which could

20 be a manmade or natural reflecting choice. The desired signal and interference signal travel to the receive antennas by different paths and the reflection paths are also different. It is evident that no desired signal or interference signal is correlated with any

25 other desired signal or interference.

FIG. 3 illustrates a prior art interference reduction approach used in many interference suppression systems. The radio transmitter as a WLAN unit or tag **20** sends a signal that is received by a

30 system antenna **23** and the best possible "interference" (I) is subtracted from a contaminated desired signal (S+I). A controller **24** is operative with an amplitude control circuit **26** and phase control circuit **28,** which receive the interfering signal from an interference

receiving antenna **30**. A logic circuit **32** receives the (I) signal as an interference signal and the desired signal (S) plus the interference (I) and subtracts the interference. It is shown that the amplitude and phase

5   of the interference can be controlled by minimizing the amount of interference in the output. An interference detection circuit **34** provides part of the feedback with the controller **24** for adjusting the amplitude control circuit **26** and the phase control circuit **28**. The

10 interference receiving antenna **30** can be a high gain antenna that has its beam directed at the source of interference.

This prior art solution is not effective when the interference signal would be disbursed in time, as

15 happens in a real world reflective environment dominated by multipath effects. The present invention is effective to provide a solution in real time location systems (RTLS) and wireless local area networks.

20   In accordance with the present invention, phase-temporal interference suppression accommodates a wide variety of multipath distortion on the interference signal. When the interference signal is disbursed over time, disbursed over angle of arrival

25 and of a random phase, the present invention provides a different solution as compared to what is described as the prior art of FIG. 3.

FIG. 4 illustrates the importance of the present invention and how a signal can be changed with

30 only one reflection. A transmit signal is shown as one symbol length and a direct signal path and a reflection signal path as reflected from a reflector is shown. In the example shown in FIG. 4, the reflection is delayed one symbol time and the phase is 180° such that the two

signals are subtracted. The graphical representation
of the signal result on the right illustrates the
changed signal. Although only one signal reflection is
shown, there could be hundreds of reflections. Also,

5 the signal received a few wavelengths away in distance
could have a totally different waveform depending on
the nature of the reflections. To subtract any
waveform from another waveform and obtain a complete
subtraction, it is necessary to have identical signals

10 so the negative of one signal algebraically cancels the
other.

As shown in FIG. 5, the phase-temporal
interference suppression technique of the present
invention is used to accommodate the multipath

15 distortion on the interfering signal. The system
recreates a replica of the "disbursed interference," I_D
to effect a complete subtraction. As shown in the
system **40** of the present invention, a tapped delay line
42, controller **44**, summer **46**, interference detector **48**,

20 logic circuit as an adder/subtracter **50**, system antenna
51 and interference receiving antenna **52** are operative
with each other. A source of interference **16** is shown
as sending signals to the interference receiving
antenna **50**, and the system antenna **51** via a reflector

25 **54**. A radio transmitter **20**, which could be a tag
transmitter, mobile unit or mobile access point station
of a WLAN system, also transmits a signal to the system
antenna **51** that receives the desired signal plus the
interference I_D. It is evident that the system of

30 FIG. 5 recreates the signal interference no matter how
it has been disbursed in time and phase (phase-
temporal) and uses the recreated/disbursed version of
the interference to complete cancellation of the
interference on the system antenna.

The interference received at the system antenna **51** is different from the interference received at the interference receiving antenna **52**. In one aspect of the present invention, the interference

5 receiving antenna **52** is a high gain interference receiving antenna that creates the strongest signal possible by gathering as much energy as practical using an antenna of design known to those skilled in the art. Once the interference (I) is captured, it is changed to

10 a replica of the disbursed interference I_D received on the system antenna. The tapped delay line circuit **42** provides a tap-spacing (or resolution) that enables most of the symbol to be managed. One example would be on the order of one tapped symbol spacing on the taps.

15 Each possible delayed version of the interference is independently "weighted" by controlling its amplitude and phase by the functions W_1, W_2 ... W_n. The sum of all the weighted replicas can be made to a close approximation to the dispersed interference

20 received at the system antenna 51. The control over the weight functions is managed by the controller **44** whose input is received from the interference detector **48**. The control loop operates to minimize the amount of interference at the system output and supplies only

25 S at the output. The interference is removed. Control can be used by techniques known to those skilled in the art. Although interference suppression techniques are known in television systems, such as disclosed in U.S. Patent No. 5,818,517 to Hudson et al. and incorporated

30 by reference, the present invention provides substantial improvement over prior art systems used in wireless and location systems.

It is possible that a high gain antenna for the interference receiving antenna **52** is not required

under some circumstances. A replica of the
interference signal could be received on an antenna
that is identical and reasonably close in proximity to
the "system antenna." Thus, the interference receiving
5   antenna **52** could be replaced with a system antenna
having two identical antennas.

It is possible to use dual diversity for
receiving the signal as disclosed in the incorporated
by reference U.S. Patent No. 5,995,046. For example,
10   FIG. 6 illustrates a system where two system antennae
51a, 51b for channels A and B are illustrated. Two
interference detectors **48a, 48b** are used and a
controller **44** is operative with two summers **46a, 46b**
that are operative with a tapped delay line **42** that is
15   operative with a tertiary antenna **60**. By use of the
third input at a tertiary antenna **60**, interference can
be removed from both system inputs A and B. The summer
46a, 46b could contain both the weight manifold and
summing manifold. Although the block diagram
20   illustrates the basic signal flow, the system can be
used with digital, RF or other analog systems.

Another dual diversity systems with system
antennas A and B is shown in FIG. 7 with two tapped
delay lines **42a, 42b** operative with summers **46a, 46b**.
25   The controller **44** operates to remove the interference
from each side by subtracting a replica interference
received from the other system antenna **51a** or **51b** in a
bilateral symmetrical fashion to provide improved
performance to both sides.

30   It is evident that the interference
suppression system of the present invention provides
interference reduction that is optimized for crowded
wireless bands such as the 2.4 GHz band and the 5.0+
GHz bands in an environment dominated by multipath

reflections. Of course, the technique can be applied to any frequency band, as known to those skilled in the art.

The use of the interference suppression
5 system as described is operable with real time location systems (RTLS) and wireless local area networks (WLAN). It has the ability to increase co-channel use of the same frequency bands and improve the radio frequency mutual compatibility and enable these two systems to
10 co-exist more effectively in the same frequency bands.

As will now be described in detail, relative to FIGS. 1 and 1A and FIGS. 8 and 9, a location system as used with a wireless local area network and a tag location system (FIG. 1A) is described. FIGS. 8 and 9
15 show representative circuits and algorithms as also disclosed in the incorporated by reference patents that can be used with the present invention.

FIG. 1 illustrates a high level block diagram of a WLAN system **120** and showing a network server **122**
20 that is part of an ethernet local area network **124**. A plurality of access point base stations **126** each define a cell (shown as **127a, 126b, 127c**) as part of a wireless local area network **130** that communicates with wireless mobile stations (MS) using wireless
25 communication signals that, in a preferred embodiment, are spread spectrum wireless communication signals. A single mobile access point station **131** is illustrated, although a plurality of such stations could be used in the system. Reflecting surfaces **133** are illustrated
30 and usually are an annoying determent to the system. Another antenna **133a** is an interference source.

A processor **132** is operatively connected to each of the access point base stations (both fixed and wireless) and operative to process communication

signals transmitted from a mobile station and determine which signals are first-to-arrive signals, typically based on a common timing signal. A location processor conducts differentiation of the first-to-arrive signals

5   to locate the mobile station. A processor **132a** is incorporated with each access point base station in one aspect. A common timing signal can be applied to each access point base station (and to processor **132** and/or **132a**) and could be provided by a wireless timing signal

10   broadcast to each of the access point base stations, such as by a mobile station (MS) located at a known location **134** or an access point base station that provides the common timing signal. In yet another aspect of the present invention, a common timing signal

15   can be supplied through a common bus, such as part of the ethernet structure.

Mobile and/or fixed access point base stations **126, 131** each have a wireless local area network (WLAN) receiver **136** for receiving

20   communications signals. A separate location receiver **138** could be used for receiving separate location pulses. Processors **132** and/or **132a** determine which signals are first-to-arrive signals and conduct differentiation of the first-to-arrive signals to

25   locate the mobile station. The receiver **136** can operate from the same antenna **140** or can operate in dual diversity using two antennae **140a, 140b**, as shown with the mobile access point station **131**.

Each access point station could also include

30   a plurality of mutually diverse antennas used in locating a mobile access point station or mobile station. In one aspect of the present invention, a communication signal could include a separate location packet or pulse. The location determination could

occur by processing part of the normal data or by processing packets that are used specifically for locating the mobile access point station.

A communication signal transmitted from a
5 mobile access point station **122** could include a spread spectrum location pulse appended to the wireless communication signal that could be of short duration, typically less than a one millisecond, spread spectrum transmission as a location pulse, which is distinct and
10 different from the wireless local area network communication signal. This location pulse could be appended to the falling edge of the wireless communication signal or appended to the beginning or rising edge of the communication signal.
15 The mobile devices or stations in communication with a mobile access point station or mobile station could transmit location data as appended pulses as forth in the incorporated by reference copending patent application serial no. 09/997,282,
20 filed November 29, 2001. A mobile access point station could also add any signaling and location information as determined by those skilled in the art. Although direct sequence spread spectrum communication signals are preferred, different spread spectrum signals could
25 be used, including any type of location pulse, frequency hopping, chirp or other spread spectrum signal techniques. Location transmitters and location receivers with appropriate communication circuitry, as set forth in the incorporated by reference patents and
30 copending patent application, can be included as part of any mobile station or access point station as determined by those skilled in the art. It is also possible to use a network management station (MMS) operative under simple network management protocol
35 (SNMP) and operative with a management information base

(MIB). The positive characteristics for objects corresponding to access point stations and other devices associated with a wireless local area network system could allow management control by a network
5   management station.

FIG. 1A illustrates an environment where a plurality of tags **170** are associated with objects **171**, such as items of inventory for manufactured objects in a factory corresponding to a monitored environment **180**
10 as a non-limiting example. A plurality of spaced, monitoring receivers **172** receive signals from tag transmitters **170** and include processors (not shown in detail) for receiving the signals from the tag transmitters and determining which signals are first-
15 to-arrive signals. These spaced monitoring receivers **172** are operative with an RF location processor system **174** to conduct differentiation of the first-to-arrive signals to locate an object and its associated tag **170**. The processing system **174** is operative with an Asset
20 Management Database **176** and computer **178** as described in the above-identified and incorporated by reference patents.

Referring now to FIGS. 8 and 9, a representative circuit and algorithm as described in
25 the above mentioned and incorporated by reference patents are disclosed and set forth in the description below to aid in understanding the type of location system that can be used for determining which communication signals are first-to-arrive signals and
30 how the processor conducts differentiation of the first-to-arrive signals to locate a mobile station, TAG, access unit or other device. This processor (or an associated processor) could also be operative as noted before for weighting the delayed versions of at

least one interference signal by controlling amplitude and phase with weighted functions W_1, W_2 ... W_n and summing weighted replicas to determine an approximation of the dispersed interference for cancelling

5   interference.

FIG. 8 diagrammatically illustrates one type of circuitry configuration of a respective architecture for "reading" associated communication signals or a pulse (a "blink") used for location determination

10 signals, such as signals emitted from a mobile station (M), a TAG, or a mobile access point station that is to be located. An antenna **210** senses appended transmission bursts or other signals from the mobile access point station to be located. The antenna in

15 this aspect of the invention could also be omnidirectional and circularly polarized and coupled to a power amplifier **212**, whose output is filtered by a bandpass filter **214**. Respective I and Q channels of the bandpass filtered signal are processed in

20 associated circuits corresponding to that coupled downstream of filter **214**. To simplify the drawing only a single channel is shown.

A respective bandpass filtered I/Q channel is applied to a first input **221** of a down-converting mixer

25 **223**. Mixer **223** has a second input **225** coupled to receive the output of a phase-locked local IF oscillator **227**. IF oscillator **227** is driven by a highly stable reference frequency signal (e.g., 175 MHz) coupled over a (75 ohm) communication cable **231**

30 from a control processor. The reference frequency applied to phase-locked oscillator **227** is coupled through an LC filter **233** and limited via limiter **235**.

The IF output of mixer **223**, which may be on the order of 70 MHz, is coupled to a controlled

equalizer **236**, the output of which is applied through a controlled current amplifier **237** and applied to communication cable **231** through a communication signal processor, which could be an associated processor as

5   described before. The communication cable **231** also supplies DC power for the various components of the location receiver by way of an RF choke **241** to a voltage regulator **242**, which supplies the requisite DC voltage for powering an oscillator, power amplifier and

10 analog-to-digital units of the receiver.

The amplitude of the (175 MHZ) reference frequency supplied by the communications control processor to the phase locked local oscillator **227** implies the length of any communication cable **231** (if

15 used) between a location processor and a receiver, such as if part of an access point station or other device. This magnitude information can be used as control inputs to equalizer **236** and current amplifier **237**, so as to set gain and/or a desired value of equalization,

20 that may be required to accommodate any length of a communication cable (if used). For this purpose, the magnitude of the reference frequency may be detected by a simple diode detector **245** and applied to respective inputs of a set of gain and equalization comparators

25 shown at **247**. The outputs of comparators are quantized to set the gain and/or equalization parameters.

FIG. 9 diagrammatically illustrates the architecture of a correlation-based, RF signal processor circuit as part of a processor to which the

30 output of a respective RF/IF conversion circuit of FIG. 8 can be coupled for processing the output and determining location. The correlation-based RF signal processor correlates spread spectrum signals detected by an associated receiver with successively delayed or

offset in time (by a fraction of a chip) spread spectrum reference signal patterns, and determines which spread spectrum signal received by a receiver of an access point station is the first-to-arrive

5   corresponding to a location pulse or communications signal from the transmitter of a mobile access point station as part of the communications signal that has traveled over the closest observable path between a mobile access point station and the fixed location

10   access point station or TAG and spaced monitoring receiver.

Because each receiver can be expected to receive multiple signals from the mobile access point station or other mobile device or TAG due to multipath

15   effects caused by the signal transmitted by the mobile access point station or other device being reflected off various objects/surfaces between the mobile access point station and the receiver of other known access point stations **20**, the correlation scheme ensures

20   identification of the first observable transmission, which is the only signal containing valid timing information from which a true determination can be made of the distance from the station to the receiver.

For this purpose, as shown in FIG. 9, the RF

25   processor employs a front end, multi-channel digitizer **300**, such as a quadrature IF-baseband down-converter for each of an N number of receivers. The quadrature baseband signals are digitized by associated analog-to-digital converters (ADCs) **272I** and **272Q**. Digitizing

30   (sampling) the outputs at baseband serves to minimize the sampling rate required for an individual channel, while also allowing a matched filter section **305**, to which the respective channels (reader outputs) of the digitizer **300** are coupled to be implemented as a

single, dedicated functionality ASIC, that is readily cascadable with other identical components to maximize performance and minimize cost.

This provides an advantage over bandpass
5   filtering schemes, which require either higher sampling rates or more expensive ADCs that are capable of directly sampling very high IF frequencies and large bandwidths. Implementing a bandpass filtering approach typically requires a second ASIC to provide an
10 interface between the ADCs and the correlators. In addition, baseband sampling requires only half the sampling rate per channel of bandpass filtering schemes.

The matched filter section **305** may contain a
15 plurality of matched filter banks **307**, each of which is comprised of a set of parallel correlators, such as described in the above identified, incorporated by reference '926 patent. A PN spreading code generator could produce a PN spreading code (identical to that
20 produced by the PN spreading sequence generator of the location transmitter). The PN spreading code produced by PN code generator is supplied to a first correlator unit and a series of delay units, outputs of which are coupled to respective ones of the remaining
25 correlators. Each delay unit provides a delay equivalent to one-half a chip. Further details of the parallel correlation are found in the incorporated by reference '926 patent.

As a non-limiting example, the matched filter
30 correlators may be sized and clocked to provide on the order of 4×10^6 correlations per epoch. By continuously correlating all possible phases of the PN spreading code with an incoming signal, the correlation processing architecture effectively functions as a
35 matched filter, continuously looking for a match

between the reference spreading code sequence and the contents of the incoming signal. Each correlation output port **328** is compared with a prescribed threshold that is adaptively established by a set of "on-demand"

5   or "as needed" digital processing units 340-1, 340-2, ..., 340-K. One of the correlator outputs **328** has a summation value exceeding the threshold in which the delayed version of the PN spreading sequence is effectively aligned (to within half a chip time) with

10 the incoming signal.

This signal is applied to a switching matrix **330**, which is operative to couple a "snapshot" of the data on the selected channel to a selected digital signal processing unit **340-i** of the set of digital

15 signal processing units **340**. The mobile access point station can "blink" or transmit location pulses randomly, and can be statistically quantified, and thus, the number of potential simultaneous signals over a processor revisit time could determine the number of

20 such "on-demand" digital signal processors required. A processor would scan the raw data supplied to the matched filter and the initial time tag. The raw data is scanned at fractions of a chip rate using a separate matched filter as a co-processor to produce an

25 auto-correlation in both the forward (in time) and backwards (in time) directions around the initial detection output for both the earliest (first observable path) detection and other buried signals. The output of the digital processor is the first path

30 detection time, threshold information, and the amount of energy in the signal produced at each receiver's input, which is supplied to and processed by the time-of-arrival-based multi-lateration processor section **400**.

Processor section **400** uses a standard multi-lateration algorithm that relies upon time-of-arrival inputs from at least three detectors of the access point stations **20** or other devices to compute the

5 location of the mobile access point station **22**, or in other embodiments, locate a TAG or mobile station, such as a cellular phone, pager or other device. The algorithm may be one which uses a weighted average of the received signals. In addition to using the first

10 observable signals to determine object location, the processor also can read any data read out of a memory for the mobile access point station (or mobile device or other device if applicable) and superimposed on the transmission. Object position and parameter data can

·15 be downloaded to a data base where object information is maintained. Any data stored in a mobile station memory may be augmented by altimetry data supplied from a relatively inexpensive, commercially available altimeter circuit. Further details of such circuit are

20 found in the incorporated by reference '926 patent.

It is also possible to use an enhanced circuit as shown in the incorporated by reference '926 patent to reduce multipath effects, by using dual antennae (as shown generally with dual antennae **140a**,

25 **140b** in FIG. 1) and providing spatial diversity-based mitigation of multipath signals. In such systems, the antennas of each location receiver at an access point station are spaced apart from one another by a distance that is sufficient to minimize destructive multipath

·30 interference at both antennas simultaneously, and also ensure that the antennas are close enough to one another so as to not significantly affect the calculation of the location of the object by the downstream multi-lateration processor.

The multi-lateration algorithm executed by
the location processor **24** is modified to include a
front end subroutine that selects the earlier-to-arrive
outputs of each of the detector pairs as the value to
5   be employed in the multi-lateration algorithm. A
plurality of auxiliary "phased array" signal processing
paths can be coupled to the antenna set (e.g., pair),
in addition to the paths containing the directly
connected receivers and their associated first arrival
10   detectors that feed the triangulation locator
processor. Each respective auxiliary phased array path
is configured to sum the energy received from the two
antennas in a prescribed phase relationship, with the
energy sum being coupled to associated units that feed
15   a processor as a triangulation processor.

The purpose of a phased array modification is
to address the situation in a multipath environment
where a relatively "early" signal may be canceled by an
equal and opposite signal arriving from a different
20   direction. It is also possible to take advantage of an
array factor of a plurality of antennas to provide a
reasonable probability of effectively ignoring the
destructively interfering energy. A phased array
provides each site with the ability to differentiate
25   between received signals, by using the "pattern" or
spatial distribution of gain to receive one incoming
signal and ignore the other.

The multi-lateration algorithm executed by
the location processor could include a front end
30   subroutine that selects the earliest-to-arrive output
of its input signal processing paths and those from
each of the signal processing paths as the value to be
employed in the multi-lateration algorithm (for that
receiver site). The number of elements and paths, and

the gain and the phase shift values (weighting coefficients) may vary depending upon the application.

It is also possible to partition and distribute the processing load by using a distributed

5   data processing architecture as described in the incorporated by reference 6,127,976 patent. This architecture can be configured to distribute the workload over a plurality of interconnected information handling and processing subsystems. Distributing the

10 processing load enables fault tolerance through dynamic reallocation.

The front end processing subsystem can be partitioned into a plurality of detection processors, so that data processing operations are distributed

15 among sets of detection processors. The partitioned detection processors are coupled in turn through distributed association processors to multiple location processors. For mobile access point station (or mobile device) detection capability, each receiver could also

20 be equipped with a low cost omnidirectional antenna, that provides hemispherical coverage within the monitored environment.

A detection processor filters received energy to determine the earliest time-of-arrival energy

25 received for a transmission, and thereby minimize multi-path effects on the eventually determined location of a mobile device. The detection processor demodulates and time stamps all received energy that is correlated to known spreading codes of the

30 transmission, so as to associate a received location pulse with only one mobile. It then assembles this information into a message packet and transmits the packet as a detection report over a communication framework to one of the partitioned set of association

35 processors, and then de-allocates the detection report.

A detection processor to association control processor flow control mechanism equitably distributes the computational load among the available association processors, while assuring that all receptions of a

5 single location pulse transmission, whether they come from one or multiple detection processors, are directed to the same association processor.

The flow control mechanism uses an information and processing load distribution algorithm,

10 to determine which of the association processors is to receive the message, and queues the message on a prescribed protocol coupling socket connecting the detection processor to the destination association processor. To select a destination association

15 processor, the information and processing load distribution algorithm may include a prime number-based hashing operation to ensure a very uniform distribution of packets among association processors. In addition, to provide relatively even partitioning in the case of

20 widely varying transmission rates, the hashing algorithm may use a sequence number contained in each transmission.

Each association processor can organize its received message packets by identification (ID) and

25 time-of-arrival (TOA), and stores them as association reports. The association processor compresses the data within the association report, transmits that information over an association communication process of the communication framework to one of a plurality of

30 distributed location processors, and then de-allocates the association report.

In order to deliver all association reports that have been generated for an individual mobile access point station (or other mobile or location

35 device) to a single destination location processor, the

association communication process of the communication framework may employ the same information and processing load distribution algorithm executed by the detection communication process of the communication

5   framework. Each location processor determines the geographical location of a mobile access point station (or other mobile or location device) using the time-of-arrival measurement information originally sourced from the detection processors. The specific algorithm

10   employed for location determination matches the number of arrival time measurements with whatever a priori information is available.

        To locate a mobile access point station (or other mobile device or TAG), a processor may employ all

15   available diversity information associated with the mobile of interest, including, but not limited to the station ID (if any), any data contained in the transmission and metrics indicating confidence it these values. It then forwards a location report containing

20   this information over a location communication process to an asset management data base. A location estimate may be derived from the measured time-of-arrival information in a received association report packet, using a differential time-of-arrival algorithm, such as

25   a hyperbolic geometry-based function.

        It is also possible to use a wireless local area network (WLAN) spread spectrum waveform to perform a geo-location function. The assumption is that the wireless communication signal, as a spread spectrum

30   signal, has a high signal-to-noise ratio with reasonable power levels. The leading edge of this communication signal can be detected to a high accuracy and this information used with the algorithms as described before to provide relative time of arrival

35   information for subsequent processing. It is possible

to use edge detector circuitry as part of an access point station having a wireless local area network (WLAN) receiver. It is also possible to have a timing signal from a known location or unknown location.

5   Other component locations could be known, of course. For example, some wireless local area network (WLAN) transmitters have known locations to enable the use of the algorithm when an access point station or other mobile station or device location is known.

10   It is also known that the communications signal as a spread spectrum communications signal can have sufficient bandwidth to provide useful time accuracy. For example, a 50 MHz bandwidth could provide approximately 5 nanoseconds of timing accuracy

15   that is about 5 feet of accuracy using much of the technology and teachings described before. It is possible to use a correlator operative as a functional spread spectrum matched filter to enable a higher quality estimate with integration over many chips of

20   the spread spectrum transmission. It is possible to use a matched filter that spans multiple symbols and improves accuracy by collecting more energy in the filter prior to leading edge detection.

          It is evident that the present invention that

25   uses the phase-temporal interference processing (PTIP) system for interference suppression is applicable to many different types of wireless local area networks and real time location systems. Although the described real time location system and wireless local area

30   network described above are non-limiting examples, they are representative of the type of systems used with the present invention.

          Many modifications and other embodiments of the invention will come to the mind of one skilled in

35   the art having the benefit of the teachings presented

in the foregoing descriptions and the associated
drawings. Therefore, it is to be understood that the
invention is not to be limited to the specific
embodiments disclosed, and that the modifications and
5   embodiments are intended to be included within the
scope of the dependent claims.